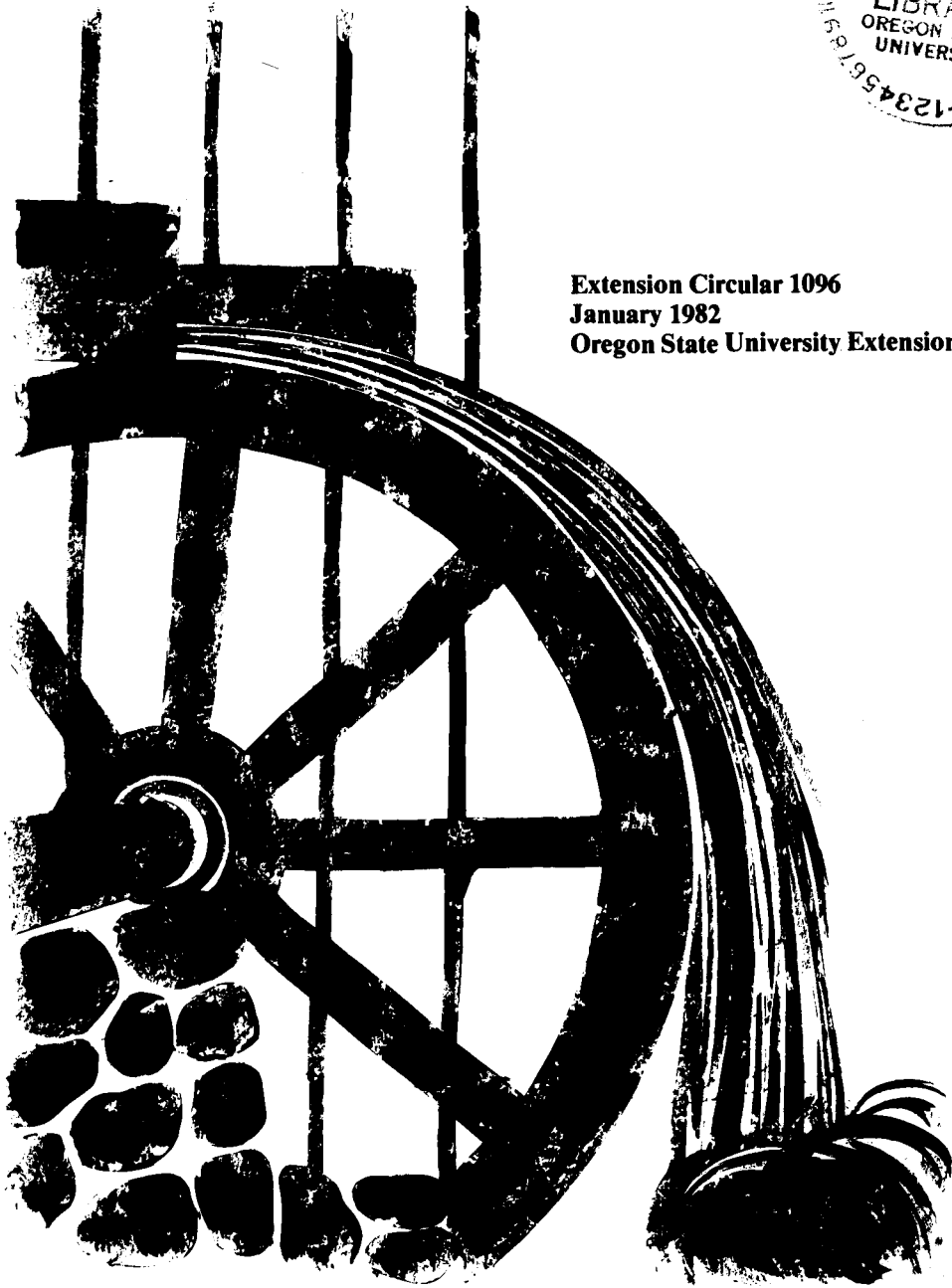


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# Micro-Hydropower: *Oregon Development Guide*



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# Micro-Hydropower: Oregon Development Guide

Hydropower is not new. Thousands of years ago man discovered that water could be persuaded to work for him. First, it carried heavy loads. Then, the power of falling water was transferred to a spinning shaft used to operate nearby equipment. It wasn't until 1882 that water was first used to generate electricity. Since then, hydroelectric plants have gotten bigger and electricity distribution lines have gotten longer. Currently, existing hydropower offers the least costly form of electricity in the Pacific Northwest.

Today, many potential hydropower sites remain undeveloped. Some of these are sites that were abandoned when "low-cost" electric utility power became available; other sites have not been developed for economic or environmental reasons. However, the economic situation has been changing in recent years. Now people are taking a serious look at reclaiming abandoned hydro sites and developing new ones.

The effect of hydropower development on the environment is still an important concern for many people. This has led to an increasing interest in the development of smaller sites that would have minimal effects on the environment and on other water users. This circular focuses on small systems that might provide electricity for a home, farm, or ranch. These are referred to as micro-hydroelectric systems, or "micro-hydro" for short, and would generate less than 100 kilowatts.

If you are considering the development of a micro-hydro site, this circular is intended to help you get started. The first two sections of this circular present steps you can take to determine the potential of your hydroelectric site and to make a preliminary determination of feasibility. These steps are important before you spend any money on equipment and construction. If your

site proves to be feasible, the third section outlines steps in the development process. An example is included at the end of the circular that shows how these steps are applied to a typical micro-hydro site.

A typical micro-hydro system is built around a turbine and generator. Water turns the turbine, converting streamflow to mechanical energy. The energy can be used to operate nearby equipment directly or to turn an electric generator. Some of the basic system components are shown in Figure 1. Other components which might be found in a typical system include a turbine-speed governor, control circuitry, and, in some cases, storage capabilities, such as batteries or a pond.

Micro-hydro has its own language. Defining terms is a good place to begin an understanding of micro-hydro.

**Total available head** is the difference in elevation between the water level at the dam or diversion and the turbine site. Head is usually expressed in feet.

**Flow** is the volume of water passing a given location in a given time. Flow is usually expressed in gallons per minute (gpm), cubic feet per minute (cfm), or cubic feet per second (cfs).

**Head loss** is a collective term for friction and turbulence losses in the piping system, and is usually expressed as the equivalent amount of feet of head lost. Head loss increases with pipe length, roughness, flow rate, and decreasing pipe diameter. For example, short, smooth, large-diameter pipe has less head loss than long, rough, small-diameter pipe.

**Net head** is determined by subtracting head loss from the total available head. Between 5 and 25 percent of the total available head is typically lost in the piping system.

**Power** is a measure of ability to do work and can be expressed in kilowatts (kW). Power from a hydroelectric system is the product of head and flow.

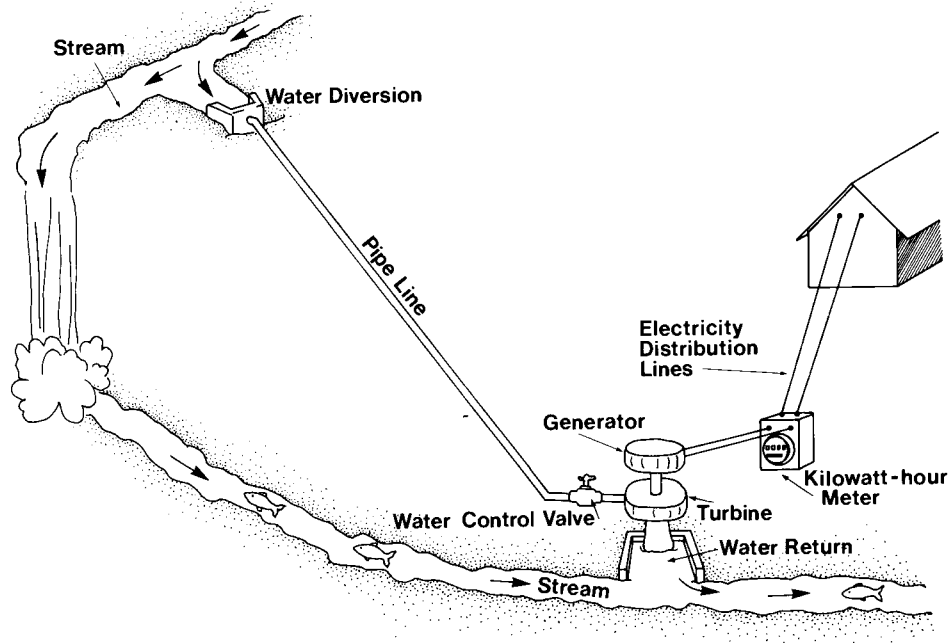


Figure 1. Components of a typical micro-hydro system.

Therefore, a high-head, low-flow site can produce the same power as a low-head, high-flow site. One major difference is that the larger equipment required for a high-flow site is usually more expensive.

*Energy* can be thought of as a running total of power over time. Energy can be

expressed in kilowatt-hours (kWh) and is what you buy from — or could sell to — the electric utility. For example, a hydroelectric system generating at a 10-kilowatt (kW) *power* output for one hour will produce 10 kilowatt-hours (kWh) of electrical *energy*.

*Efficiency* is defined as the ratio of

power output to power input. Some of the power available will be lost because of friction, power conversion, and related losses in the turbine and generator. These losses vary with the equipment selected and with the head and flow available at the site at any given time.

# Resource Assessment

Developing a micro-hydro system involves several important tasks. One of the most critical is assessing the energy potential of your stream. Seven steps are required in this task.

You can complete these steps with very little help from others. Most can be done within a day or two, but measuring flow and calculating power and energy will require follow-up work over a longer period to obtain representative streamflow information.

## 1. Select Site

The first step in planning a hydroelectric system is finding a suitable site. A stream and adjacent land for the piping and power house are necessary. The power house should be close to where you will use the electricity unless you plan to build a transmission line.

The best site provides the greatest head in the shortest distance. If the streamflow is small and there is little available head, the site may not provide enough power to meet your needs. Where the ground slope is sufficient, a water wheel or turbine may be used. However, in most cases a total head of 10 feet or more would be required for a feasible system.

## 2. Check Development Constraints

There may be environmental, fishery, or navigational problems associated with developing your micro-hydro site. Poor geological conditions or soil erosion may be a problem. Plant and animal life may be limiting factors. Other considerations include neighbors and others along the stream who could be affected by construction or operation of your system.

Learn what you can and cannot do. This is important to know before you

spend much time or money on designing your system. For example, how much water must be left in the stream? Are fish ladders or screening required? Is a micro-hydro system compatible with local zoning or land-use planning? The Oregon Departments of Water Resources, Fish and Wildlife, Land Conservation and Development, and Energy can help identify potential problems. You have a responsibility to avoid environmental damage or harm to other water users.

## 3. Plan System Layout

If you have choices about where to locate the water diversion, turbine, and water return, this is the time to decide on a tentative system layout. The intake should be placed where it will not be blocked by debris and where a fish screen and/or fish ladder could be installed if needed. The water return should let the "used" water reenter the stream without eroding the bank or flooding the turbine. The turbine should be low enough to give the greatest possible head, yet be high enough to avoid being flooded.

A sketch or drawing with pertinent dimensions will be very useful. Later, in seeking a license, you will need detailed drawings to describe the locations of water diversions, use, and return. Your drawings should show property lines

and reference points. Ground stakes will be necessary for accurate measurements.

## 4. Measure Head

You can make an accurate measurement or a rough estimation of the total available head at your site, depending on the equipment you use and the time and care you take. Initially, only a rough estimate is needed; later in the site development process, an accurate measurement will be necessary. You can use the following two techniques to determine head.

**Incremental Elevation Method.** One technique is to use a carpenter's level and a 2" x 2" about five feet long to do some rough survey leveling. Use the 2" x 2" as a vertical stand to support the level in a horizontal position. Measure the height from top of the level to bottom of the 2" x 2" and use this length as the incremental height for each sighting.

Start at the proposed powerhouse location and sight horizontally along the level at a rock or other object along the route. It will be one increment of height above the starting point. Then move the 2" x 2" and level to the reference object, and sight along the level to find a new reference object along the line of sight. The new object will be an increment of height above the

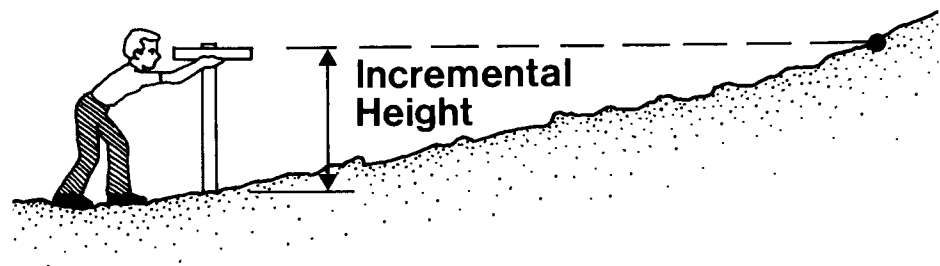


Figure 2. Incremental elevation method of measuring total available head.

previous point. Repeat this procedure until you reach the point of water diversion. Then add the incremental heights to get the available head.

**Level and Rod Method.** When a more accurate measurement of available head is needed later, a similar technique can be used with an improvised rod (such as a 1" x 2" rod 8 to 10 feet long, marked in feet and inches). This will allow shorter, more reliable sightings. The level and rod are moved alternately. Two people are required.

Still better estimates can be obtained using a surveying level or transit and leveling rod.

## 5. Measure Flow

Streamflow varies with the weather and the season. For energy production, it is *very important* to know or to estimate how the flow varies at different times of the year and from year to year. The minimum flow allows you to estimate the most power you could generate during the dry season without building a storage reservoir. The larger winter flows allow you to estimate the highest power available, as well as to protect the system from flood damage. How flow variability is used to determine system size and annual energy production is included in the example at the end of this circular.

There are many ways to measure flow rates. These depend on stream size, number of measurements required, and desired degree of accuracy. Four methods for measuring flow rates follow.

**Streamflow Gaging Stations.** Many streams and rivers in Oregon have had their flow rates measured and recorded daily for many years. Contact the Oregon Department of Water Resources or your local Watermaster. If your stream has been measured near your site, you can request streamflow data and proceed to the section on calculating power.

**Container Filling Time.** If the flow is small, you may be able to use a bucket or barrel of known size and a watch with a second hand to measure the time required to fill the container. Dividing the container volume by the filling time gives the flow rate. For example, if the filling time for a 55-gallon drum placed under a culvert

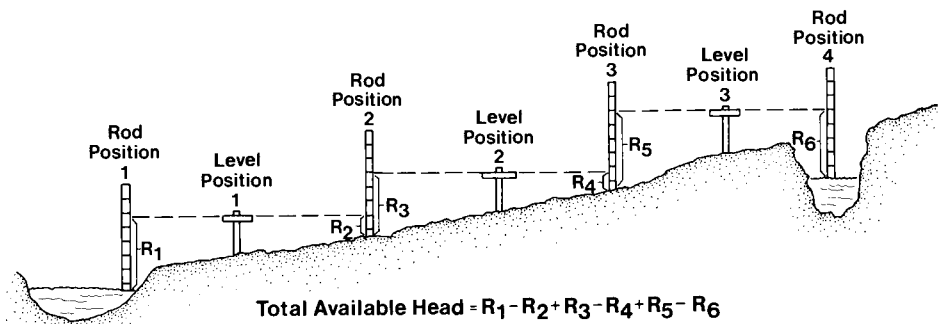


Figure 3. Level and rod method of measuring total available head.

were 20 seconds, the flow rate would

$$\text{be } \frac{55 \text{ gal}}{20 \text{ sec}} = 2.75 \frac{\text{gal}}{\text{sec}} \times 60 \frac{\text{sec}}{\text{min}} = 165 \text{ gpm.}$$



$$\text{Flow } Q = \frac{\text{Container capacity}}{\text{Filling time}}$$

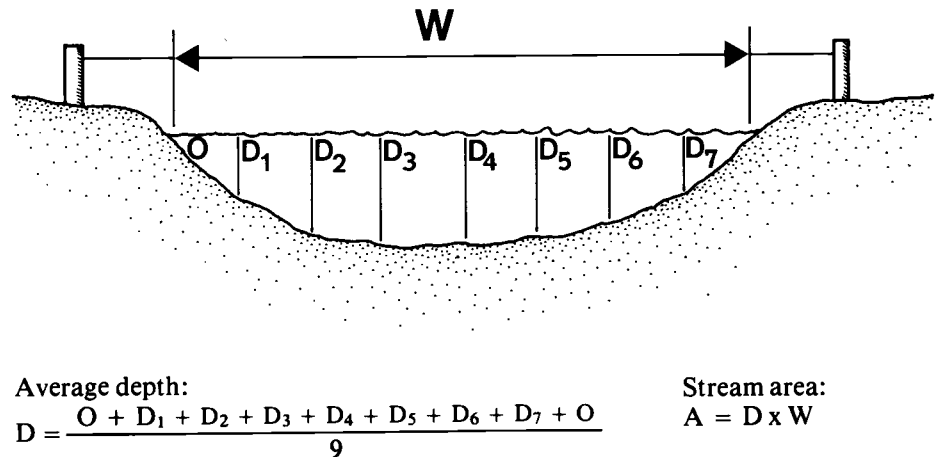
Figure 4. Container filling time method of measuring streamflow.

**Float Method.** The flow can also be estimated using a watch, tape measure, weighted float, and calibrated stick such as a yardstick for shallow streams. A

weighted float can be made using a piece of wood with one end weighted with some heavy material — such as nails or metal scraps — or a plastic container partially filled with water. The float is partially submerged to obtain a better estimate of the average stream velocity, but should not touch the bottom of the stream.

Begin by finding a stretch of stream as straight and as uniform in width and depth as possible. Pick a typical section and measure the stream width (W) with the tape measure. Use the calibrated stick like a ruler to measure the depth at 6-inch intervals across the stream. Nine depth measurements are shown in Figure 5, including two zero measurements at the stream banks. Average these depths to estimate the average stream depth (D). Multiply the average depth by the stream width to estimate the stream area (A).

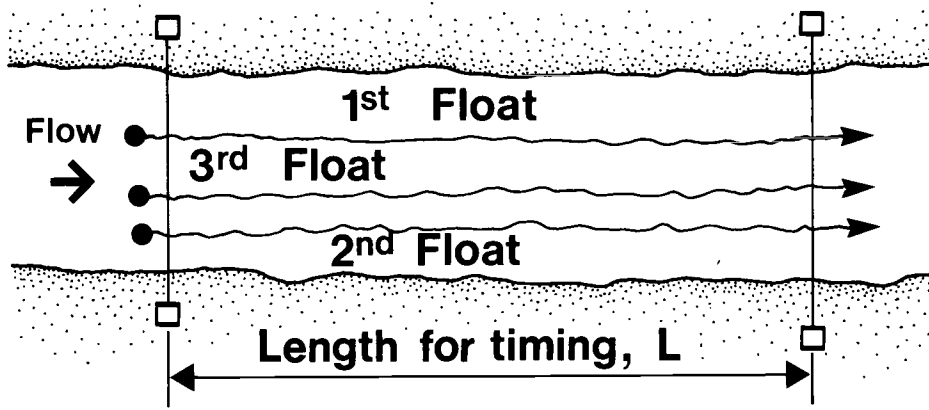
Next, measure along the stream for 20 or more feet and mark off start and



$$\text{Average depth: } D = \frac{O + D_1 + D_2 + D_3 + D_4 + D_5 + D_6 + D_7 + O}{9}$$

$$\text{Stream area: } A = D \times W$$

Figure 5. Measuring stream area.



Average time:  

$$T = \frac{T_1 + T_2 + T_3}{3}$$

Stream velocity:  

$$V = \frac{L}{T}$$

Stream flow:  

$$Q = A \times V \times C$$

Figure 6. Float method of measuring average stream velocity.

finish lines for a float “race course.” Throw the weighted float in the water just above the starting line. Time the float’s travel between markers. Repeat several times at different distances across the stream’s width. Use the average time and the measured distance to calculate the average velocity.

The flow can be calculated from the equation:

$$Q = A \times V \times C,$$

where

- Q = water flow rate,
- A = stream area,
- V = average stream velocity, and
- C = correction factor.

The flow equation includes a correction factor to account for streambed conditions. Use  $C = 0.6$  for a rough or rocky streambed;  $C = 0.8$  for a smooth streambed; or  $C = 0.7$  for intermediate conditions.

Flow is calculated in cubic feet per second (cfs), based on area in square feet and velocity in feet per second. For other units of measure, see the conversion table at the end of this circular.

**Weir Method.** Flow measurements must be made several times over the year to determine flow variability. For rough estimates, several measurements may do, using the float method, for example. But remember that both the stream area and the velocity change with flow rate — so that depth, width, and velocity must be measured each time.

For more convenient measurements, you could build a weir across the stream. A weir is a very low dam which is used to measure streamflow.

The weir itself can be quite simple—an existing spillway, a plank with a notch, a log, or a row of large boulders across the stream. The weir should provide a stable sill over which the stream flows and should cause the water to back up a few inches at the upstream side.

The weir will allow you to determine the relationship between the water level at a staff gage (vertical post calibrated in

inches), located about 5 feet upstream from the weir, and the corresponding flow in the stream. Once this relationship is established, you will be able to determine flow rates simply by reading the water level at the staff gage.

There are two ways to establish the relationship between flow and water depth by means of a weir. The first is to build a weir with a notch of specified width and depth. The relationship between flow and water depth at the staff gage can be read from weir tables. Notch weir construction details and table are given in recommended readings 1 and 5 listed at the end of this circular. The other weir method uses a calibration curve, which is established by carefully measuring the flow and the water depth at the staff gage for high, intermediate, and low flow conditions. A calibration curve is established in the example at the end of this circular.

## 6. Estimate Power Potential

The available power can be calculated for the measured head and flow rate. Head may vary only slightly over the year, but flow will change significantly. So, what flow do you use to calculate power? The answer is whatever flow is diverted through your turbine. In the example, design flow is selected for two types of hydroelectric systems—fixed flow and variable flow.

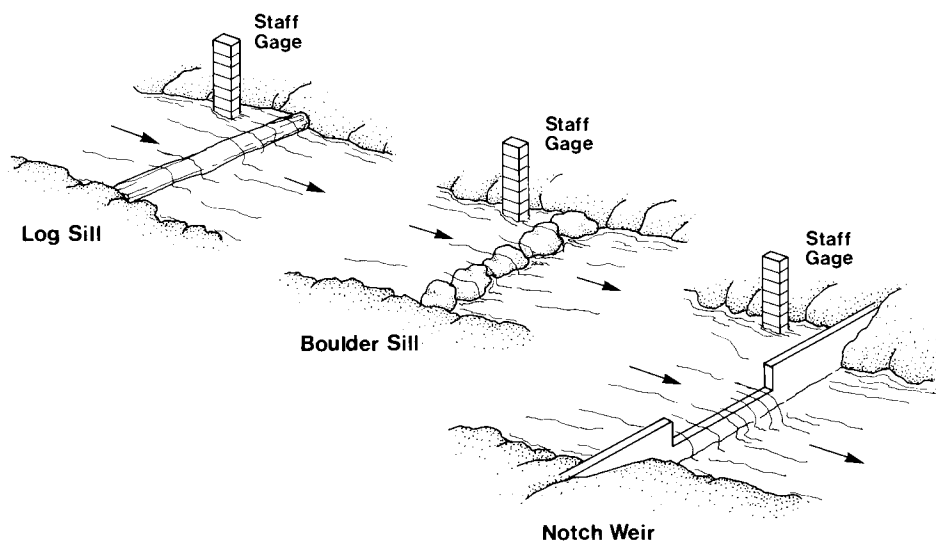


Figure 7. Types of weirs.

The net power for a given head and flow can be calculated from the following equation:

$P = 0.0846 \times Q \times H \times e$ ,  
where  $P$  = power in kilowatts,  
 $Q$  = flow rate in cfs,  
 $H$  = net head in feet, and  
 $e$  = machinery efficiency  
(use  $e = 0.5$  for initial estimate).

When using the power equation, the efficiency must be estimated. Since you have not yet selected the particular equipment to produce power, a cautious estimate—such as 50 percent—is

reasonable. You can refine this after you have selected actual equipment.

## 7. Estimate Annual Energy Production

Energy is calculated as the product of power and time. If you know or can estimate the streamflow rates for different times of year, you can calculate the power which could be produced at these times. By summing these power levels, multiplied by the number of hours they are available, the annual energy production can be calculated, using the energy equation:

$E = P \times t$ ,  
where  $E$  = energy in kWh,  
 $P$  = power in kW, and  
 $t$  = time interval in hours.

But, it's not that easy. Rainfall varies from year to year as well. If the year during which you made your measurements was wetter than average, then you may overestimate your energy potential. You may want to use average flows over many years, or check newspapers or local weather sources to compare the rainfall during the measurement year with average rainfall.

Annual energy production is included in the example.

# Preliminary Feasibility

After completing the previous steps, you should know if a potential site exists, if you will be entitled to use the water, and how much power and energy your system could supply. Now you may want to consider the question: Is a micro-hydro system capable of satisfying your energy requirements successfully?

To answer this question you will need to determine: (1) your requirements, and (2) your definition of success. The following steps offer some help in determining feasibility for your site.

## 1. Compare Energy Supply and Demand

This section only applies if you plan to develop a hydroelectric system independent of the electric utility lines. The most common reason for installing an independent system is to avoid the cost of building a transmission line to existing, but distant, power lines. In this case your hydroelectric and possibly your backup system must meet your peak power demand as well as your average demand. How you estimate your demand will depend on whether or not you now have electric utility power.

**Electric Utility Power.** This section is for you if you plan to install a micro-hydro system at a remote site or perhaps disconnect your present home from the electric utility. If you have electric power now, the easiest way to calculate your average demand is from

your electric bill. Divide the "kWh consumed" number by the number of hours in the billing period to get the average demand in kilowatts (kW). The average demand for Oregon residences is about 1.5 kW.

Peak demand will be larger than the average demand because people use more energy at busy times of the day, such as meal or laundry times, and less at other times, such as when sleeping. Perhaps the easiest way to estimate peak demand is to read your electric meter at half-hour intervals, especially at times of high energy use. Contact your electric utility if you need help reading the meter. Divide the difference in the meter readings over each 30-minute period by 1/2 hour to get the kW demand for that period. For example, if your electric meter recorded 7 kWh of energy used during a busy 30-minute period, the demand for that period would be  $7 \text{ kWh} \div 1/2 \text{ hr} = 14 \text{ kW}$  demand. The largest demand reading recorded for any half-hour interval would be your peak demand.

**Independent.** If you do not presently have electric utility power, then you will need to estimate your average and peak demand. You will need the rating of the appliances you plan to use and the estimated length of time you use them. Appliance ratings can often be found on the appliance. Appliance rating charts can also be found in references 1 and 6 in the recommended reading list, or from your nearest electric utility office.

Compare power production from your system with your demand. An independent system must provide for your peak demand. If there is not enough power available to meet your peak demand, you might consider two alternatives. One alternative is a change of your energy consumption pattern to reduce peak demand by using energy more uniformly over the day. The other alternative is an energy storage system—such as a pond or batteries—or a back-up generator to increase peak supply.

A comparison of energy supply from your system and your energy demand could have an important bearing on your final system components, including decisions about additional power sources and energy storage.

## 2. Consider Electric Utility Interconnection

There are many advantages to interconnection. One is that the electric utility will supply any additional power needed to meet your demand—at least for the present. No back-up power or energy storage system is required. For this reason, interconnected systems are usually less expensive. Another advantage is that state and federal laws require electric utilities to buy any excess power you may wish to sell, with some qualifications. In most cases, this results in larger returns on your investment than from independent systems. For these reasons most

hydroelectric installations will be interconnected.

If you are considering interconnection, you should check with your electric utility early in the development process. They have standards that your system must meet regarding safety and the quality of power produced. The cost of the equipment required to meet these standards can be considered a disadvantage. Nevertheless, in most cases interconnection remains the most effective alternative.

The electric utility can also provide information on the purchase rate for your excess energy. It may differ from the rate at which they sell energy. These requirements and rates are important to know for determining economic feasibility for your system.

### 3. Determine Cost

There are six main tasks which require time and money: resource assessment; feasibility study; system design; permits and financing; equipment selection; and installation. You can hire people to perform any or all of these tasks, including installing a complete system—or you may wish to perform any or all of them yourself. The cost will vary accordingly.

Equipment manufacturers, suppliers, and consultants may be helpful at this point. They may be able to estimate costs for any or all assistance or equipment you require, or they may be able to provide equipment literature and reference information to help you to estimate likely costs. At present, typical costs for feasible systems range from \$1000 to \$3000/kW installed.

The Oregon Department of Energy maintains a list of equipment manufacturers and suppliers. You should compare several estimates before selecting a micro-hydro system.

### 4. Check Tax Incentives

Tax credits can greatly reduce the cost of your system, but credits change from year to year. Contact the Internal Revenue Service for information on federal hydroelectric tax credits.

The State of Oregon allows two different tax credits for hydro projects. One is for a residential installation, and the other is for business applications. Oregon tax credits apply only to

money spent after your tax credit application is approved.

Another incentive is exemption of energy production facilities from property taxes. For details on tax incentives in Oregon, contact the Oregon Department of Energy.

### 5. Investigate Financing

Financing a small hydroelectric system will take some effort on your part. Most conventional lenders are not familiar with the technology involved.

There are several sources that you should know about. You may be able to finance your system through the Department of Veterans Affairs State Home Loan Program. Farmers Home Administration and other federally subsidized lenders such as the Federal Land Bank may also be sources of financing if you operate a farm or ranch.

The State of Oregon offers financing through the Small Scale Energy Loan Program (SELP). The interest rates vary depending on bond sales, but generally are lower than private financing. For micro-hydro projects, the loan period varies from 10 to 20 years. Check with the Oregon Department of Energy for information on this source of financing. It may prove to be one of the least expensive sources of money, and the program is designed to encourage small energy projects.

### 6. Economics

A hydroelectric system will probably affect your economic situation for the next 20 years or more. The next step is to determine whether those effects will be positive or negative.

Economic models applicable to long term investments require projections of interest, inflation, and energy price escalation rates over the life of the investment. However, in times of rapid economic change any long term project is subject to a high degree of uncertainty. So what model can you use?

One economic model is to compare the amount of your annual loan payment with the net energy savings from your system. This model assumes that you borrow the money to install your micro-hydro system. A 20-year loan is assumed here, although you could also determine the annual

payments for a longer or shorter loan. Your lending institution can tell you what interest rate to expect for a given loan period for the cost of your system. The following example shows how to apply payment factors to estimate annual payments, including principal and interest, on a 20-year loan.

| Interest rate (%) | Payment factor: |
|-------------------|-----------------|
| 8                 | 0.102           |
| 10                | 0.117           |
| 12                | 0.134           |
| 15                | 0.160           |
| 20                | 0.205           |

#### Annual Payments:

|                        |                   |
|------------------------|-------------------|
| Net System Cost... C = | \$8,000*          |
| Interest Rate..... I = | 12%*              |
| Payment Factor... F =  | 0.134             |
| Annual Payment.. A =   | F x C             |
|                        | = 0.134 x \$8,000 |
|                        | = \$1070          |

Now compare the annual payment with the energy savings from your system. For this comparison, you will need the value of the energy in \$/kWh (from electric utility) and your estimated annual energy production. The value of other annual expenses, such as operation, maintenance, and liability insurance (if required), should also be estimated.

#### First-year Savings:

|                            |   |
|----------------------------|---|
| Energy Production..... E = | 21,600 $\frac{\text{kWh}}{\text{year}}$ * |
| Energy Value..... V =      | \$.04/kWh*                                |
| Energy Savings..... S =    | V x E                                     |
|                            | = \$.04 x 21,600                          |
|                            | = \$864/year                              |
| Annual Expenses... X =     | \$100*                                    |
| Net Savings..... N =       | S - X                                     |
|                            | = \$864 - \$100                           |
|                            | = \$764/year                              |

#### Benefit Ratio:

$$B = \frac{N}{A} = \frac{764}{1070} = 0.71$$

If the benefit ratio is less than one, as in the above example, the system is a loser in the first year. This investment

\* Assumed values for purposes of example.



should be considered carefully. It *could* be justified *economically* if two conditions are satisfied: (1) projections of energy value increases show that the investment will yield a positive return over the system lifetime; and (2)

alternatives fare no better.

On the other hand, if the benefit ratio is greater than one, your savings will exceed costs the first year. Because the annual loan payments are fixed, and the energy value will probably increase each

year, the benefit ratio will increase with time. Such an investment would be to your benefit. However, other alternatives, including conservation measures, might yield greater benefits and should also be considered.

# Development

After completing the preliminary feasibility steps, you should have learned if your micro-hydro system will meet your needs, roughly how much it will cost after tax credits, how you will finance it, and if it can be justified by at least one economic model. If development still is promising, you will want to consider five additional steps.

## 1. Review of Layout and Energy Assessment

A definite location for your system should be selected. The total available head should be remeasured accurately. Additional streamflow data may be needed. The power and energy estimates should be refined as new or better data permit.

If you don't already own all of the site you want to develop, acquire it through purchase, lease, or easement.

## 2. Complete Detailed Design

Design includes the layout and sizing of the equipment involved, and the choice and detailing of structural parts of the system. Erosion protection, debris and fish screening, fish ladders if needed, flow bypasses, and water diversion must be included at this point. Visits to people who have small hydro systems will be particularly helpful, since they have already faced similar problems. The Watermaster may know of existing micro-hydro sites in your area.

The data you have already compiled will help suppliers identify the type of equipment that best meets your needs. If they are nearby, they may be willing to visit your site. Many are too far away to make a visit unless you are willing to reimburse their time and travel expenses. Some suppliers are more knowledgeable than others. Check on a supplier's qualifications, experience,

reputation, and references before spending any money.

If you are considering any type of dam, be cautious. Construction of a dam is complicated. Large dams may have a significant environmental impact. Special state and federal laws apply. You must own or control all flooded land. And, in the event of an accident, you will be liable for all damages.

The U.S. Soil Conservation Service may be able to help with specifications and designs for dams. Engineering plans and specifications are required for dams which will be over 10 feet high or will impound more than 9.2 acre-feet of water. The Oregon Department of Water Resources can also be helpful at this point with state requirements for dams and diversions, as well as special restrictions on your stream.

## 3. Resolve Doubts

You should be ready to make your decision at this point. Review the alternatives available for meeting your energy needs. Remember, a small hydroelectric installation is only one of several options. Conservation is cheaper than new generating capacity. Resolve your doubts before you develop the project.

## 4. Apply for Hydroelectric License

A hydroelectric license will be required from the Oregon Water Resources Department. The license grants the right to construct, operate, and maintain the project facilities. If water from your project will be used for other purposes (domestic, irrigation, etc.), a separate water right will be required.

Contact your local Watermaster's office or the Oregon Department of

Water Resources for a hydroelectric license application. Based on your specific plans, they will advise you of the appropriate forms needed. There will be modest fees involved when you submit the completed documents.

Federal licensing may be required if your project: (1) involves federal lands; (2) uses water from a government dam; (3) affects interstate commerce, including connection to any electric utility system; or (4) is on a navigable waterway. Check with the Federal Energy Regulatory Commission (FERC) to see what licensing may be required in your case.

## 5. Install Your Micro-Hydro System!

# Example

Let's actually take the steps outlined in the Resource Assessment and Preliminary Feasibility sections of this circular for a hypothetical site. Your site will be different, but the procedure should be similar.

## Resource Assessment

**1. Select Site.** Consider a site in the foothills of the Oregon Coast Range. Your site has a stream that is approximately 6 feet wide. The water has been at least 4 inches deep for 8 months of the year for the past 2 years, and has not dried up for as long as the oldtimers can remember. The stream drops about 50 feet in the 1000 feet it flows across your land.

Your home is all-electric, and the monthly bills have encouraged you to consider hydroelectric generation.

**2. Check Development Constraints.** You check with the Watermaster and find that all of the water is available for use if you return it to the same stream. The district Fish and Wildlife office says that there are no fish restrictions on your section of stream. And the county planning office finds that a hydroelectric project is consistent with zoning regulations and the land-use plan.

Your project encounters no insurmountable barriers; you proceed with further investigations.

**3. Plan System Layout.** Water can be diverted into a pipe near the upper end of your land; no dam is needed. The pipe can be buried and can run straight downhill for 1000 feet to a powerhouse, located on the stream bank approximately 100 feet from the house (see Figure 1). No extra voltage transformers are required.

**4. Measure Head.** You decide to make head measurements with the level and rod method as shown in Figure 3 and you obtain the results shown in Table 1. Add the net elevation changes for each level position to obtain the total available head.

Total available head is 52' 0"; however, some of the head will be lost in the pipe. Initially, head loss can be estimated at 10 percent. This means that you use a net head of 90 percent of total

Table 1.

| Level position | Backsight (B) | Foresight (F) | Net elevation change (B—F) |
|----------------|---------------|---------------|----------------------------|
| 1              | R1 = 10' 6"   | R2 = 2' 0"    | 8'6"                       |
| 2              | R3 = 12' 2"   | R4 = 1'10"    | 10'4"                      |
| 3              | R5 = 11'10"   | R6 = 0' 6"    | 11'4"                      |
| 4              | R7 = 13' 0"   | R8 = 0' 9"    | 12'3"                      |
| 5              | R9 = 12' 8"   | R10 = 3' 1"   | 9'7"                       |
| Totals         | 60' 2"        | 8' 2"         | 52'0"                      |

available head in the following calculations. For most installations, this estimate will be accurate to within 10 percent. Your estimate can be refined when actual pipe specifications are obtained.

In this example, net head is assumed constant:

$$H = 0.9 \times 52 \text{ feet} = 47 \text{ feet.}$$

**5. Measure Flow — Weir Method.** There are many ways to measure flow. In this example, you choose to obtain the annual streamflow record using the weir method. Your approach is to build a notch weir and to establish a calibration curve for your weir (see Figure 7).

The depth of the stream in inches at the staff gage should be recorded whenever you take a reading. The more often you read the depth at the staff gage, the more accurate your streamflow record will be.

In this example, you record the staff gage readings once each week on a graph for 1 year. A line is fitted to the weekly points to include an estimate for days not measured.

The water depth at the staff gage is not directly useful; you must also establish the relationship between staff gage reading and streamflow rate. To establish the following calibration curve, you measure the streamflow at

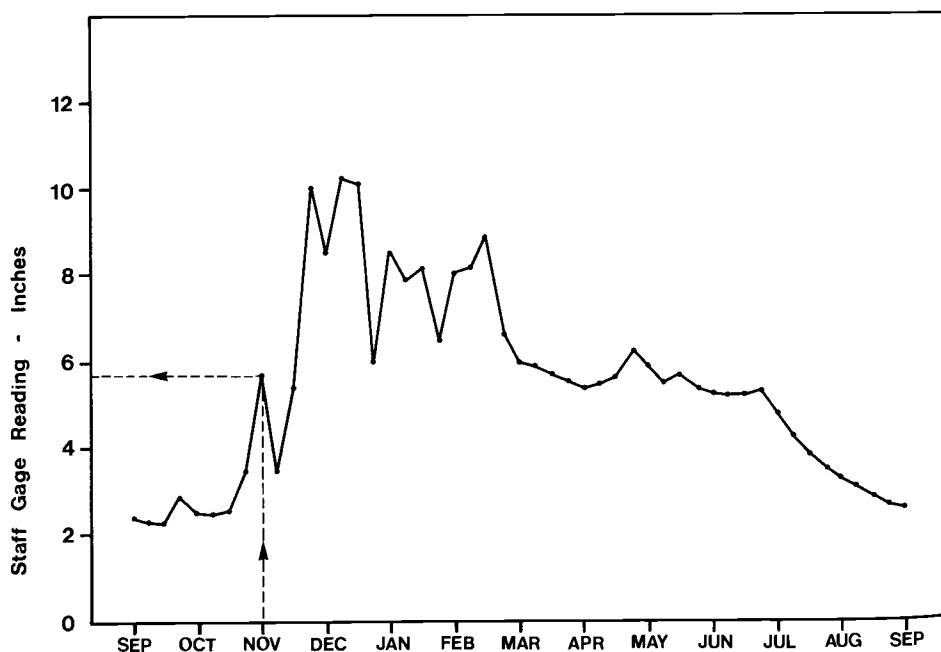


Figure 8. Annual record of staff gage readings.

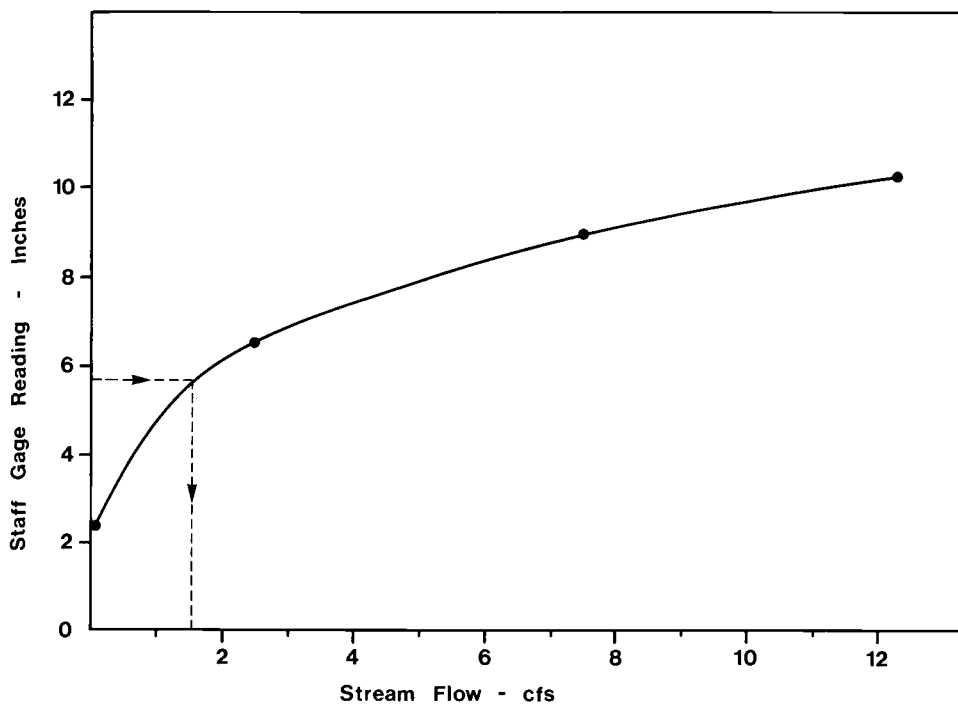


Figure 9. Weir calibration curve.

four widely differing rates using the float method (see Figure 6). These measurements are plotted versus the staff gage reading at the time of flow measurement. After fitting a curve to these four measurements, you can read a flow rate for any staff gage reading within the calibration range.

Using the calibration curve (Figure 9), convert the staff gage reading in inches to stream flow in cfs for each

measurement date. The resulting streamflow profile is also expressed on a graph.

The dashed lines on Figures 8 through 10 were added to clarify the process. For example, Figure 8 shows that on November 1 the water depth at the staff gage was 5.7 inches. Figure 9 shows that a staff gage reading of 5.7 inches corresponds to a streamflow of 1.5 cfs. In Figure 10, a flow of 1.5 cfs is plotted

for November 1. A similar process is used for the other weekly measurements in Figure 8 until the annual streamflow record is complete.

The annual streamflow record is very important for energy production. The best information is the streamflow record measured at your site for many years. This will tell you how flow varies over wet and dry years. Since it is unlikely that you will have such a record, an approximation can be made from streamflows recorded at gaging stations near your site for many years. The Watermaster may be able to provide such gaging station records.

A less effective method to estimate long term conditions is to compare the annual rainfall with the average over many years. For example, if the rainfall during the measurement year was 20 percent above average, you could estimate that the flows you measured were also 20 percent above average. This would help you to avoid overestimating your hydroelectric potential. Rainfall records can be obtained from the National Weather Service in Portland, Oregon.

**6. Estimate Power Potential.** Power can be calculated for a given head and flow rate from the following equation:

$$P = 0.0846 \times H \times Q \times e$$

Where net head  $H = 47$  feet, flow  $Q = 2$  cfs, and system efficiency  $e = 0.5$ , power is calculated to be:

$$P = 0.0846 \times 47 \text{ feet} \times 2 \text{ cfs} \times 0.5 = 4.0 \text{ kW}$$

From Figure 10 you see that a 2 cfs flow is only exceeded for approximately 110 days in the measurement year. But when you ask how long a given power is available, you also consider power over time — or energy. Let's consider power and energy together in the next section.

**7. Estimate Annual Energy Production.** The first step is to select "design flow." This is the maximum flow the turbine and pipe can accommodate. Design flow is determined from several factors, including your requirements, available streamflow, and available turbine and pipe sizes. Design flow selection is different for two types of power systems.

*Fixed flow systems* are designed to accept a fixed flow rate for a specified length of time. Such a system would be simpler and less expensive than a

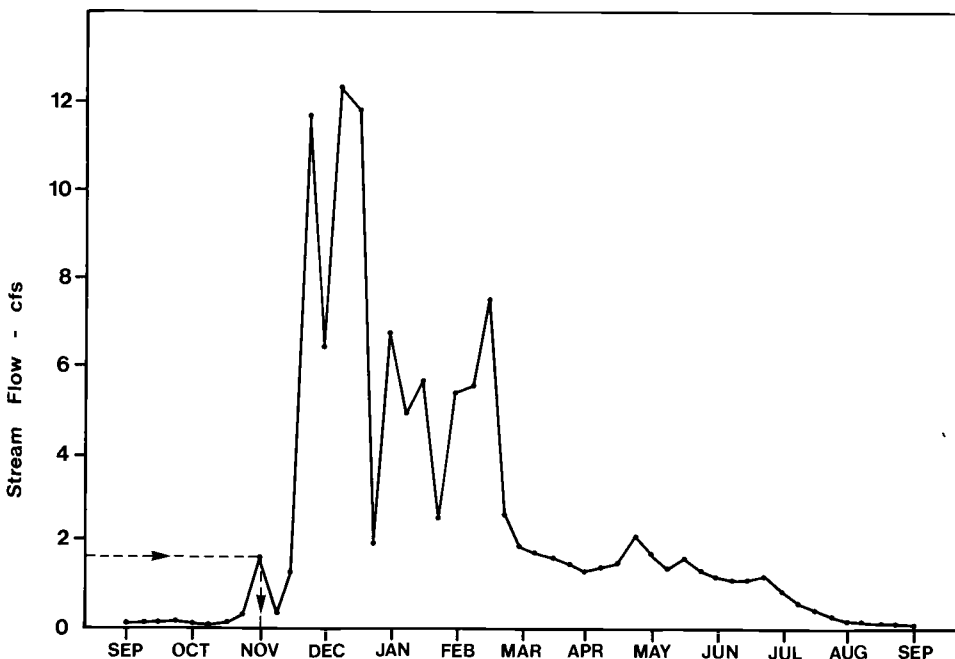


Figure 10. Annual streamflow record.

variable flow system. This might be your choice if more water power were available than you could use, sell, or afford to develop — or if insufficient waterpower were available to justify more expensive equipment.

For example, if a design flow of 0.1 cfs were chosen, Figure 10 shows that this flow would be available 365 days per year. A larger design flow of 1 cfs might better suit your needs, if you require a higher power output. But a flow of 1 cfs would only be available for 230 days. This system might be better if you have a larger electrical consumption during the months with larger streamflows.

A summary of power and energy available for three fixed flow rates is given below:

| Flow (Q)<br>cfs | Power (P)<br>kW | Available (t)<br>days | Energy (E)<br>kWh |
|-----------------|-----------------|-----------------------|-------------------|
| 0.1             | 0.2             | 365                   | 1,750             |
| 1.0             | 2.0             | 230                   | 11,000            |
| 2.0             | 4.0             | 110                   | 10,600            |

Flow availability is the number of days per year that streamflow exceeds a given flow rate (see Figure 10). Energy is calculated for a fixed flow system from the following equation:

$$E \text{ (kWh)} = P \text{ (kW)} \times t \text{ (days)} \times 24 \text{ hours/day.}$$

The power output of a fixed flow system often can be changed manually. For example, the 4-kW system in the preceding table could be operated at 4-kW power output for 110 days, and then adjusted to produce 2 kW for the next 120 (230 — 110) days. In most cases, the electric load would also have to be changed manually from 4 kW to 2 kW.

*Variable flow systems* are designed to make more efficient use of changing streamflow rates. The additional control equipment would allow more energy to be produced by automatically diverting more water when available. The result is a larger, more expensive system which would only be operating at full capacity part of the time. This might be your choice if you needed all the power you could generate, or planned to sell excess power and wanted to maximize the return on your investment.

For example, a design flow of 12.3 cfs would mean that your system would only be operating at peak capacity for 1 day per year (see Figure 10). This choice would not be economical. A more realistic design flow might be 2 cfs, which would be available for 110 days or 30 percent of the year. This choice of design flow will be used to estimate annual energy production:

$$\text{Design Flow: } Q_d = 2 \text{ cfs.}$$

It is now time to use the formulas for power and energy and the streamflow record (see Figure 10) to estimate annual energy production:

$$\begin{aligned} E &= P \times t \\ &= (0.0846 \times e \times H \times Q) \times t \\ &= 2.0 \times (Q \times t) \end{aligned}$$

with  $e = 0.5$  efficiency and  $H = 47$  feet, net head.

There are many ways to determine the volume ( $Q \times t$ ), which represents flow over time and is equal to the volume of water (in cubic feet or gallons) that passes through your turbine during time,  $t$ . One approach is to use the annual streamflow record. Begin by drawing a horizontal line on Figure 10 corresponding to the design flow,  $Q_d = 2$  cfs (see Figure 11).

Next, you need to estimate the amount of water flowing through your turbine each month, but not exceeding the design flow. To do this you can make dots such those in Figure 11 with

each dot corresponding to a chosen quantity of water. Add the total number of dots to get the annual water volume.

In this example each dot is chosen to represent a flow of  $Q_d/5$  for one month. There are 730 hours/month, so that each dot represents  $(Q_d/5 \text{ cfs}) \times 730$  hours. With  $Q_d = 2$  cfs each dot represents 1.05 million cubic feet of water per month.

The procedure is to make a dot on the streamflow record for each month for each increment of  $Q_d/5$  under the stream profile and design flow lines. In this example, the months of December, January, February, and March have five dots each, corresponding to the full design flow being available (5 dots  $\times Q_d/5 = Q_d$  available). Other months have less than the design flow available, with correspondingly fewer dots.

Finally, the volume,  $Q \times t$ , can be approximated by adding the total number of dots,  $N$ ,

$$\begin{aligned} Q \times t &= N \times Q_d/5 \times 730 \\ &= 146 \times N \times Q_d. \end{aligned}$$

The area under the curve in Figure 11 contains  $N = 37$  dots. Therefore, the annual energy production is

$$\begin{aligned} E &= 2.0 \times (Q \times t) \\ &= 2.0 \times 146 \times N \times Q_d \\ &= 2.0 \times 146 \times 37 \times 2.0 \\ &= 21,600 \text{ kWh/year.} \end{aligned}$$

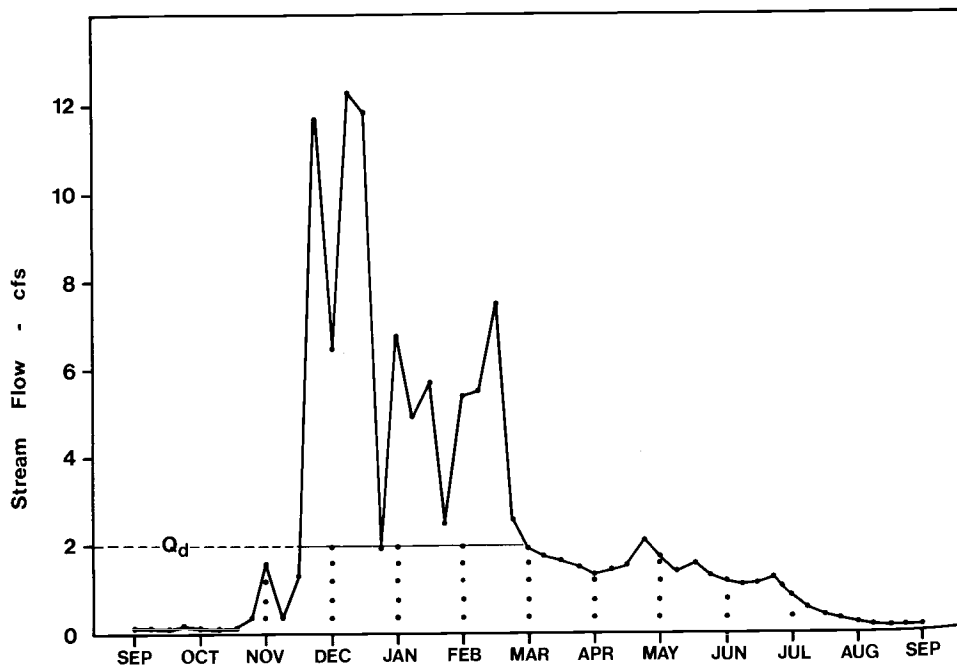


Figure 11. Estimating volume,  $Q \times t$ .

## Preliminary Feasibility

**1. Compare Energy Supply and Demand.** Power and energy production are insufficient to meet your assumed peak demand of 25 kW and energy consumption of 30,000 kWh/year. Consider interconnecting with electric utility and reduce your electric bills.

**2. Consider Electric Utility Interconnection.** Your home is already connected to the utility lines. They have agreed to buy any excess power you produce at 4¢/kWh, and sell you any power needed to meet your demand at the same rate. You will need to install an additional meter base, and switchgear for safety.

**3. Determine Cost.** After obtaining a list of hydroelectric suppliers from the Oregon Department of Energy, you invite three suppliers to bid on your installation, using your site measurements. The system which best satisfies your needs will cost \$9,000, installed.

**4. Check Tax Credits.** Tax credits change from year to year. You investigate and find that you are eligible for an Oregon residential hydro tax credit of \$1,000. Net system cost is therefore \$8,000.

**5. Investigate Financing.** The Oregon Department of Energy declared your project would be eligible for the Small Scale Energy Loan Program (SELP), provided you used the equity in your home as collateral. Based on results of a recent bond sale, they agreed to loan you \$8,000 for 20 years at 12 percent interest.

**6. Economics.** You now know how much your system will cost and have estimated how much power and energy it will produce. Is your project economically feasible? You should use your own economic model to answer that question. This example uses the model presented in the Economics section of this circular.

This model compares annual loan payments with first-year energy savings. Not coincidentally, the numbers used in the Economics section are the same numbers obtained in this example.

The result is a benefit ratio,  $B = 0.71$ . A benefit ratio less than 1 means that your project will lose money—at least for the first year.

Table 2 below shows how the benefit ratio varies with energy value for the assumptions presented in the Economics section of this circular. For example, if you could sell the energy you produce at a rate of \$.054/kWh, the benefit ratio would be 1.

With this knowledge, you have many options. Four of these are: (1) delay installation until utility rates or tax incentives rise or until system cost or interest rates fall sufficiently for the benefit ratio to exceed 1; (2) negotiate a contract with the electric utility which will allow benefits to exceed costs over the life of your system; (3) change your system, such as pipe diameter, turbine type or size, or system layout, to see if benefit ratio improves; or (4) install the system anyway, for other reasons.

Table 2.

| Energy Value (\$/kWh) | .02 | .03 | .04 | .05 | .054 | .06  |
|-----------------------|-----|-----|-----|-----|------|------|
| Benefit Ratio         | .31 | .51 | .71 | .92 | 1    | 1.12 |

# Summary

After completing the previous steps for your site, you should know the potential of your hydroelectric resource and have a preliminary estimate of feasibility. With some luck, feasibility will be a definite yes or no, but in most cases there will be doubts. Resolve your doubts before proceeding with development.

### Conversion Table

|                               |                                  |
|-------------------------------|----------------------------------|
| 1 cubic foot (cf)             | = 7.48 gallons                   |
| 1 cubic foot per second (cfs) | = 449 gallons per minute (gpm)   |
|                               | = 60 cubic feet per minute (cfm) |
| 1 meter                       | = 3.28 feet                      |
| 1 horsepower (hp)             | = 0.746 kilowatts (kW)           |

# Recommended Reading

1. Alward, Ron; Eisenbart, Sherry; Volkman, John; and Haumberger, Hans. *Micro-hydro Power: Reviewing an Old Concept*. 1979. National Center for Appropriate Technology, PO Box 3838, Butte, Montana 59701.  
This 60-page publication provides a good introduction to the subject. It includes sections on determining site potential, equipment, economics, and a list of steps to take in the development process.
2. Gladwell, John Stewart. *Small Hydro: Some Practical Planning and Design Considerations*. 1980. Idaho Water Resources Research Institute, University of Idaho, Moscow, Idaho 83843.  
This 75-page publication contains much useful information which is not available in most introductory publications. Turbines, installations, and economics are treated in detail. The treatment of site hydrology includes monthly streamflow values and the flow duration curve. This section is more technical, but valuable in determining realistic power and energy production.
3. McGuigan, Dermot. *Harnessing Water Power for Home Energy*. 1978. Garden Way Publishing Co., Charlotte, Vermont 05440.  
This 101-page book describes many aspects of micro-hydro development. It gives a number of examples of various types of water wheels and turbines.
4. Mockmore, C. A.; and Merryfield, Fred. *The Banki Water Turbine*. 1949. Engineering Experiment Station, Oregon State University, 219 Covell Hall, Corvallis, Oregon 97331.  
This short pamphlet includes sections on theory, runner construction details, and test data for a Banki/crossflow turbine. This paper is recommended for those who want to build their own.
5. Merrill, Richard; and Gage, Thomas, eds. *Energy Primer*. 1978. Portola Institute, 558 Santa Cruz Avenue, Menlo Park, California 94025.  
This comprehensive information catalog focuses on small-scale renewable energy systems. It devotes 20 pages to basic aspects of harnessing water power, including brief sections on available power, building dams, pipe and channel flows, water wheels, and turbines.
6. Leckie, J.; Masters, G.; Whitehouse, H.; and Young, L. *More Other Homes and Garbage*. 1981. Sierra Club Books, 530 Bush Street, San Francisco, California 94108.  
This book includes a 17-page introduction to hydropower. It describes techniques of measuring water flow and illustrates the basic types of dams, water wheels, and turbines.



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